W(and Z) A_N with fsPHENIX

Initial ideas by

- Brodsky, Hwang Schmidt: Single hadronic spin asymmetries in weak interaction processes, PLB553 (2003)
- Schmidt, Soffer: Transverse single spin asymmetries in gauge boson production, PLB563 (2003)

fsPHENIX working meeting 2/28/2015

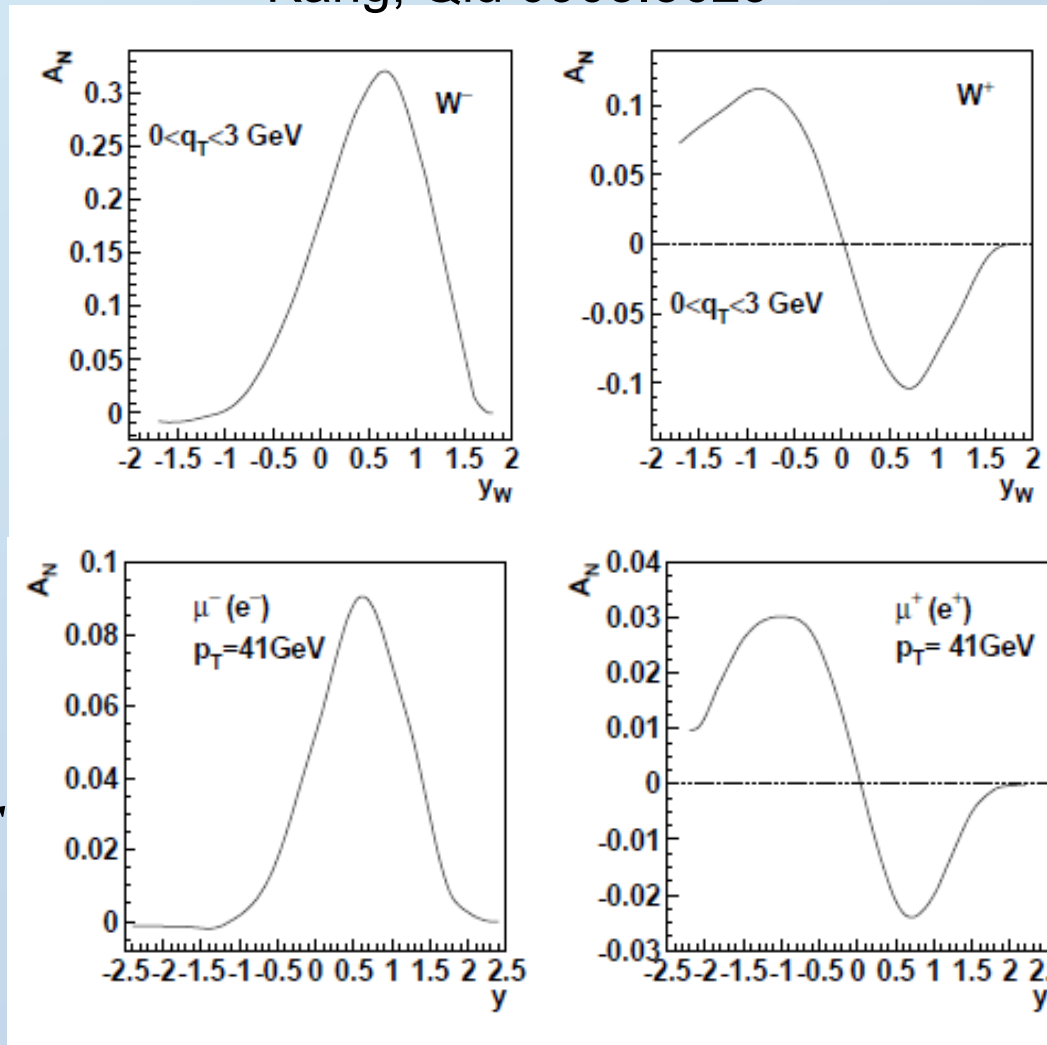
Ralf Seidl (RIKEN/RBRC)

All experimental plots + some slides taken from STAR analyzer S.Fazio (BNL)

Physics background

- W/Z A_N has no fragmentation/final state component → sensitive to Sivers function
- At small Q_T TMD formalism applicable: $Q >> Q_T >= \Lambda_{QCD}$
- Sensitivity to sign change
- Diluted asymmetries for decay leptons (but maybe still useful for run16/17 BUP?)

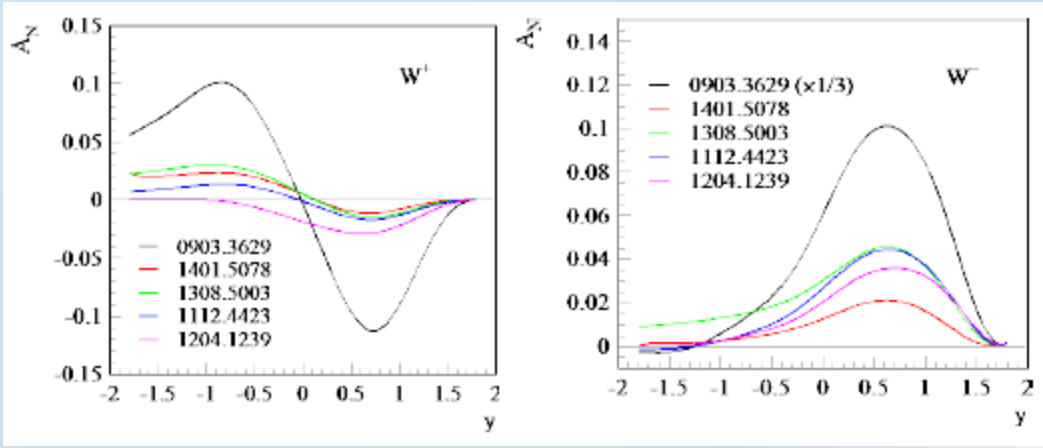
Kang, Qiu 0903.3629



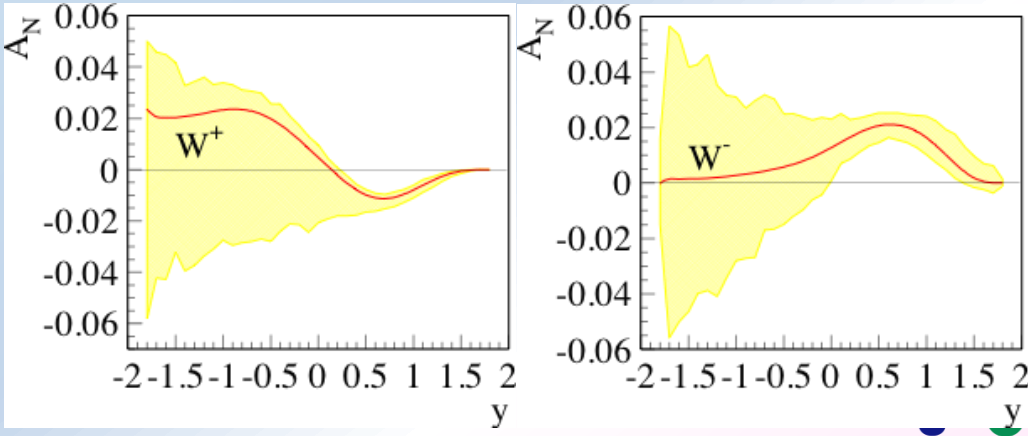
Physics background

- flavor separated sensitivity especially interesting as $\left|f_{1T}^{\perp d}\right| > \left|f_{1T}^{\perp u}\right|$ in SIDIS
- Evolution can reduce the asymmetries by factor of 10 or more
- Large uncertainties in sea quark Sivers function

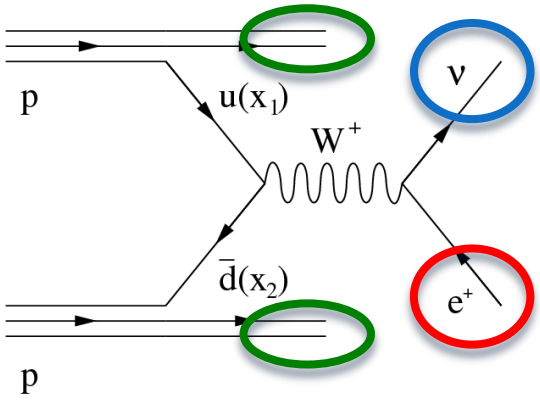
With TMD evolution



Echevarria, et al. 1401.5078



General Strategy for W A_N



$$\vec{P}_T^{\,W} \approx -\sum_{i \in \substack{tracks \\ clusters}} \vec{P}_T^{\,i}$$

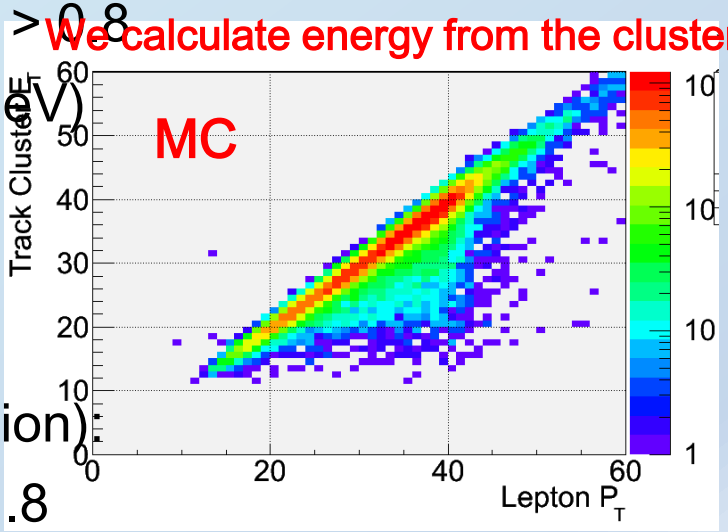
- Find W→e candidate (~40 GeV electron, missing E_T from neutrino)
- Obtain momentum sum of hadronic final state for recoil
  - Correct for missing particles at high rapidities via MC
  - Momentum balance gives P_T^W and ϕ_W .
- Solve W mass equation for longitudinal W momentum → W rapidity
- Calculate W A_N as a function of rapidity or P_T^W

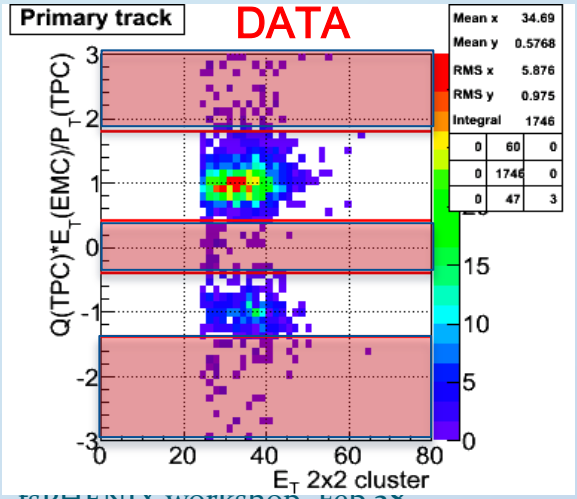
Electron identification

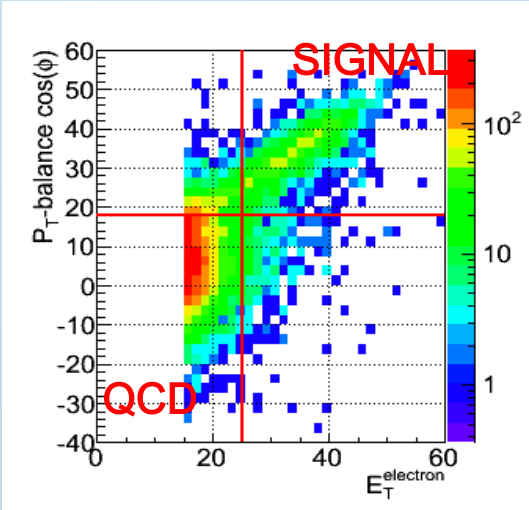
STAR analysis:
S.Fazio

- **Isolation:** (P^{track}+$E^{cluster}$) / Σ[P^{tracks} in R=0.7 cone] > 0.8
- **Imbalance:** no energy in opposite cone (E<20 GeV)
- **E_T > 25 GeV**
- Track |η| < 1
- |Z-vertex|<100 cm
- **Charge separation** (avoids charge misidentification):
  0.4 < |Charge (TPC) x E_T (EMC) / P_T (TPC)| < 1.8
- Signed P_T balance > 18 GeV (**rejects QCD Background**)

We calculate energy from the cluster





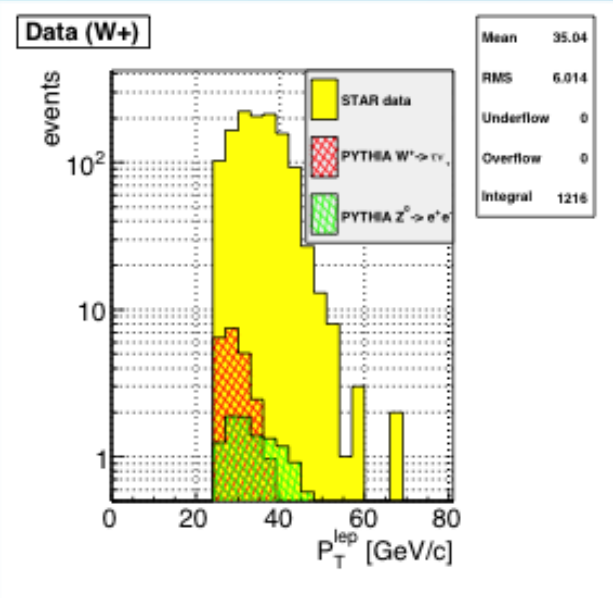


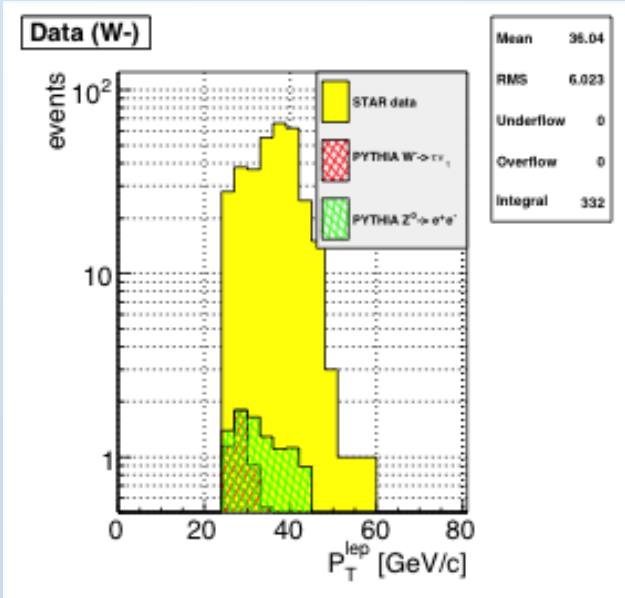
$$\vec{P}_T^{bal} = \vec{P}_T^{e} + \sum \vec{P}_T^{recoil}$$

Background estimation

STAR analysis: S.Fazio

Background estimated via MC normalized to data lumi





- Positive-charge signal 1216 events
- $Z \rightarrow ee$
- $W^+ \rightarrow t\nu_t$

W^+ sample

$Z^0 \rightarrow ee$ = 10.71 events [B/S = 0.88%]

$W^+ \rightarrow t\nu_t$ = 22.92 events [B/S = 1.88%]

- Negative-charge signal 332 events
- $Z \rightarrow ee$
- $W^- \rightarrow t\nu_t$

W^- sample

$Z^0 \rightarrow ee$ = 9.77 events [B/S = 2.94%]

$W^- \rightarrow t\nu_t$ = 4.62 events [B/S = 1.39%]

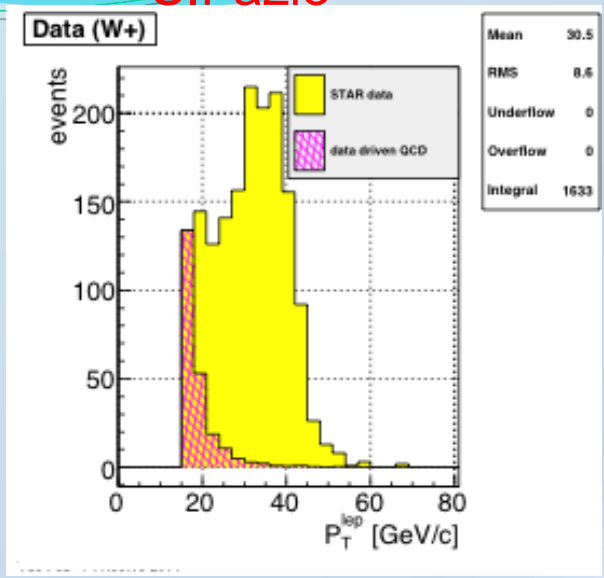
RIKEN

QCD background estimation

STAR analysis: S.Fazio

Data-driven QCD background estimation

- Reverse of P_T-balance cut [PT-balance < 15 GeV] → Selects QCD events
- Plot lepton-P_T > 15 GeV
- QCD sample normalized to the first P_T-bin [15-19 GeV]



W⁺ sample

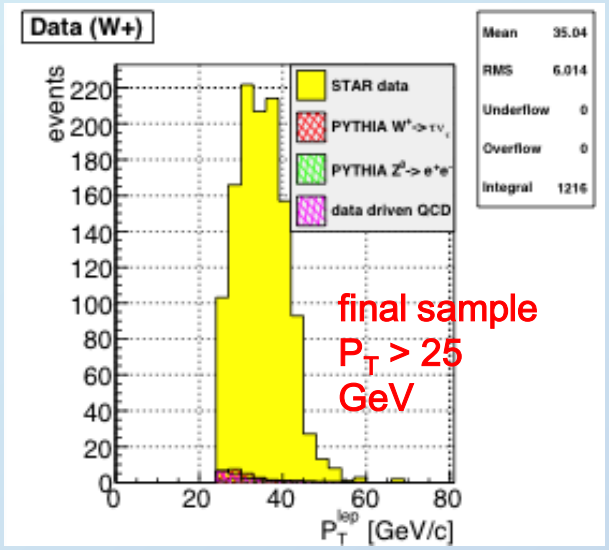
QCD = 19.37 events

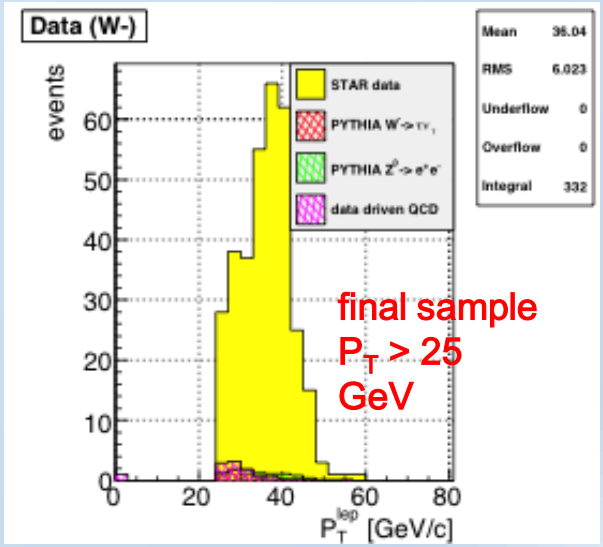
[B/S = 1.59%]

W⁻ sample

QCD = 11.30 events

[B/S = 3.40%]





COMMENTS:

- Backgrounds under control!
- Z -> e^+ e^- expected to have a comparable asymmetry

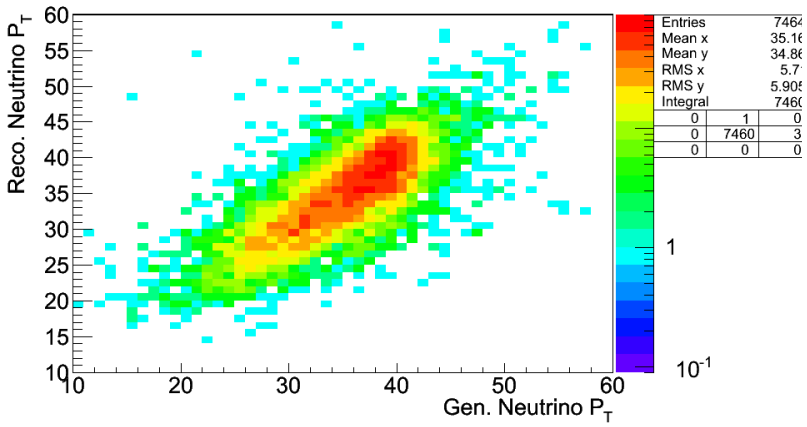
RIKEN

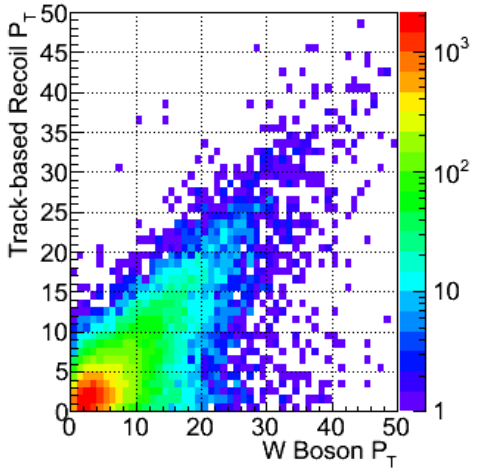
W P_T reconstruction

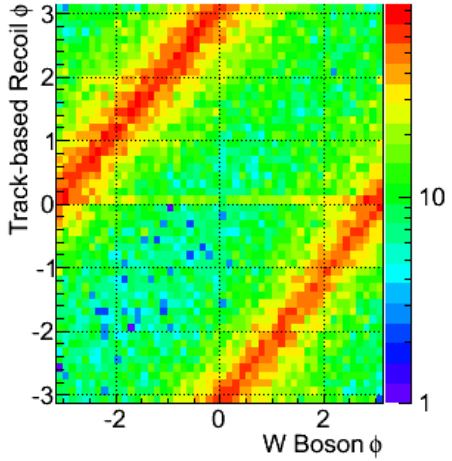
STAR analysis: S.Fazio

We calculate the recoil summing up all tracks and trackless electromagnetic clusters

- Matching track is a track which extends to the BEMC and matches a firing tower (< 7 cm)
- Trackless tower is a firing tower in the BEMC with no matching tracks and Energy > 200 MeV
- Recoil is calculated summing the momenta of all tracks which do not belong to the electron candidate + all firing trackless towers







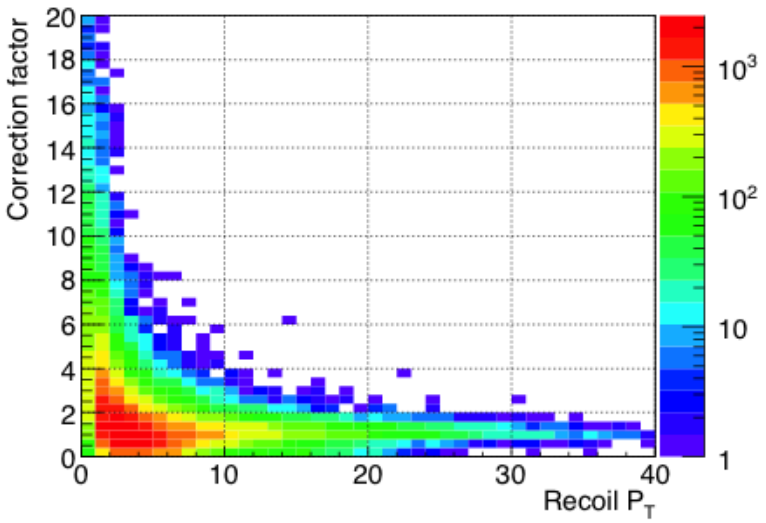
✓In transverse plane: $\vec{P}_T^{\,W} = \vec{P}_T^{\,e} + \vec{P}_T^{\,\nu} = -\vec{P}_T^{\,recoil}$

✓Recoil reconstructed using tracks and towers: $\sum_{i \in clusters}^{tracks} \vec{P}_T^{\,i}$

✓Part of the recoil not within STAR acceptance → MC correction applied

Monte Carlo correction

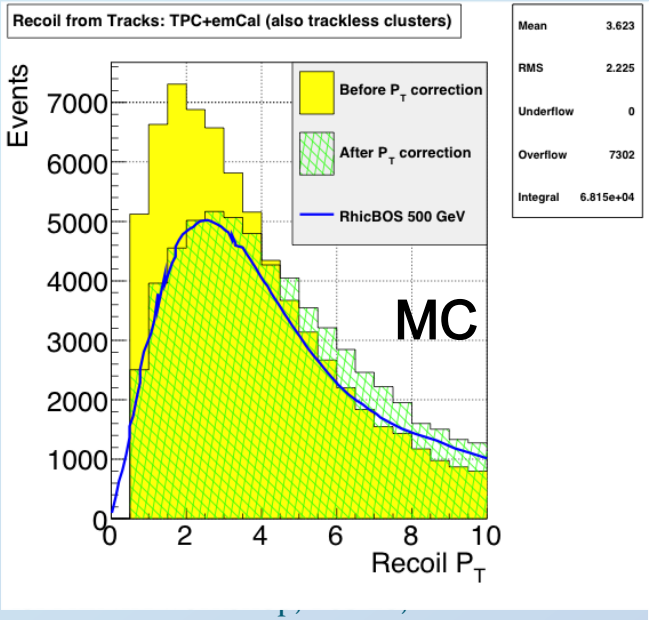
STAR analysis:
S.Fazio

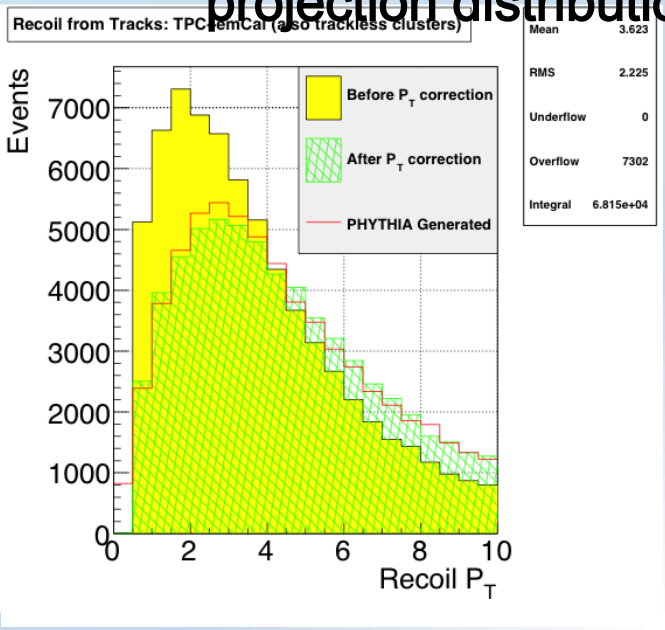


$$k_i = \frac{P_{T,i}^{W}(true)}{P_{T,i}^{\mathrm{Recoil}}(reconstructed)}$$

The Correction method –

- ✓ Read recoil P_T bin from data
- ✓ Project correction factor for corresponding P_T-bins
- ✓ Normalize the projection distribution to 1
- ✓ Pick a correction value sampled from the projection distribution





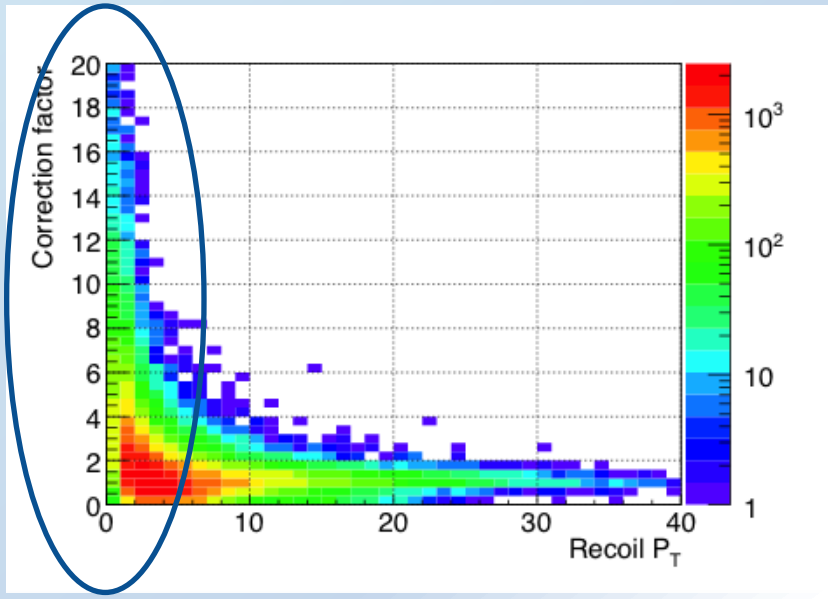
MC test:

After MC correction

→ very good agreement with RhicBOS and PYTHIA predictions

P_T correction

- Very strongly depends on the overall coverage
  - higher P_Ts: Little correction (much activity in central detectors)
  - Low P_T means recoil in beam pipe
- STAR: -1 to 2 coverage
  - Very large uncertainty/correction for lowest P_Ts
- fsPHENIX should have less correction at low P_T

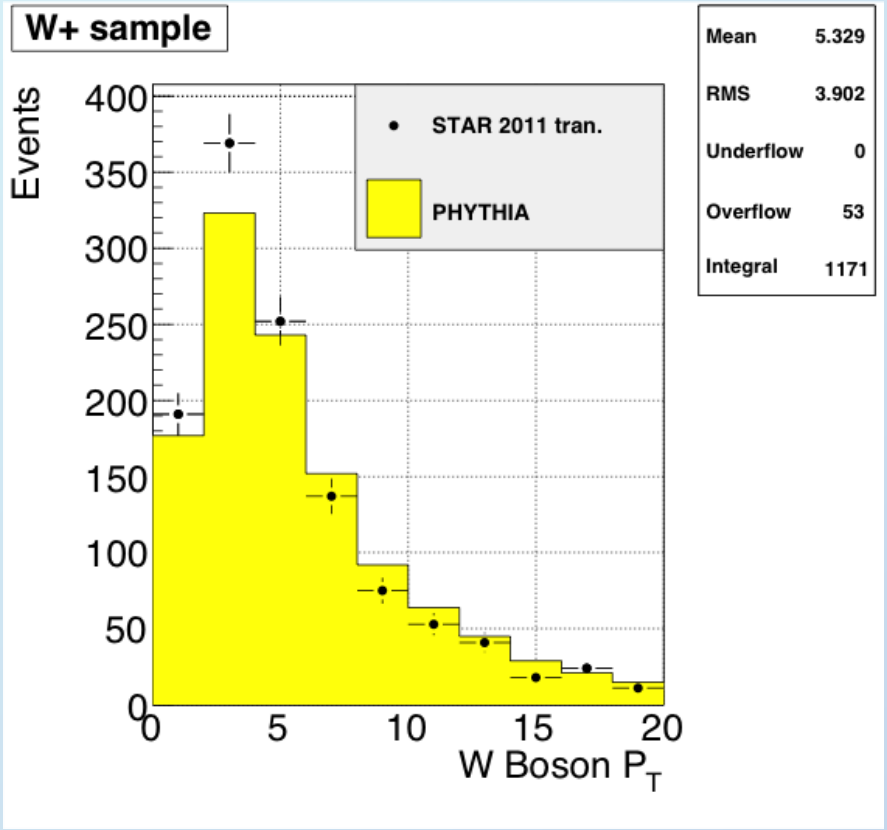


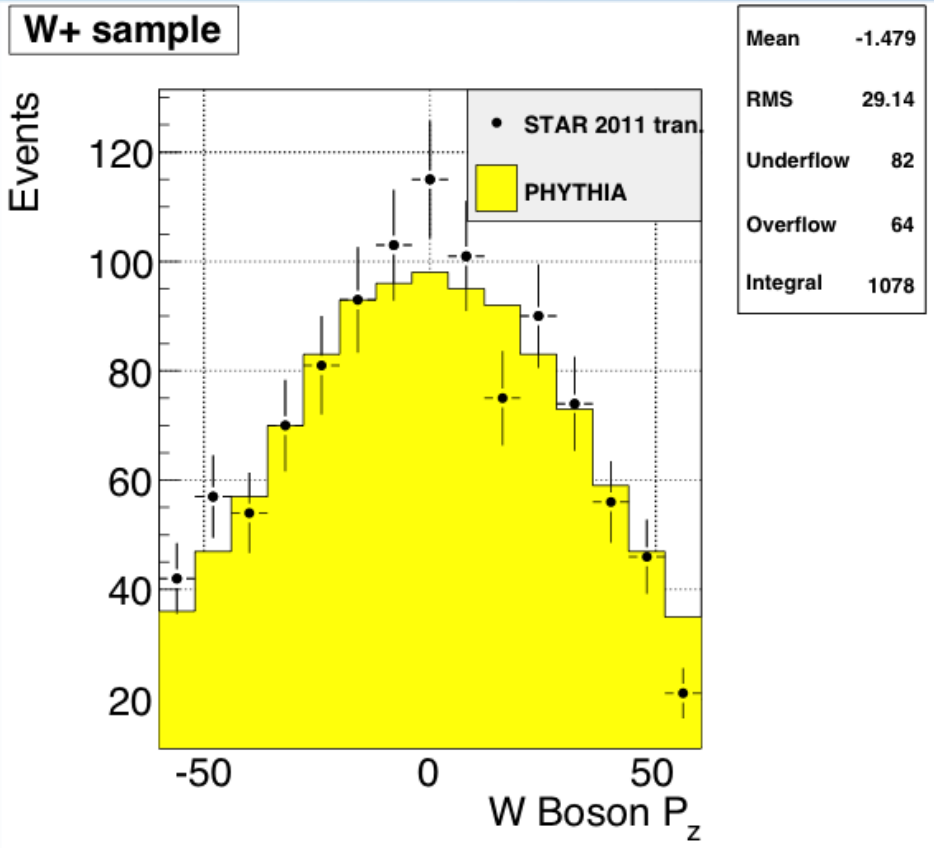
W P_T – Data/MC

STAR analysis:
S.Fazio

We add to our selection:

- Track-P_T in the recoil > 0.2 GeV
- Total recoil-P_T > 0.5 GeV





GOOD data/MC agreement after P_T correction

W P_z reconstruction

STAR analysis: S.Fazio

- ✓ W longitudinal momentum (along z) can be calculated from the invariant mass. Currently we assume constant M_W (for W produced on shell)

$$M_W^2 = \left(E_e + E_n\right)^2 - \left(\vec{p}_e + \vec{p}_n\right)^2$$

- ✓ Neutrino longitudinal momentum component from quadratic equation

$$\left|\vec{p}_T^{\,e}\right|^2 \left(p_z^n\right)^2 - 2Ap_z^e p_z^n + \left|\vec{p}_T^{\,n}\right|^2 \left|\vec{p}^{\,e}\right|^2 - A^2 = 0, \quad where \quad A = \frac{M_W^2}{2} + \vec{P}_T^{\,e} \times \vec{P}_T^{\,n}$$

- ✓ **Two solutions**!

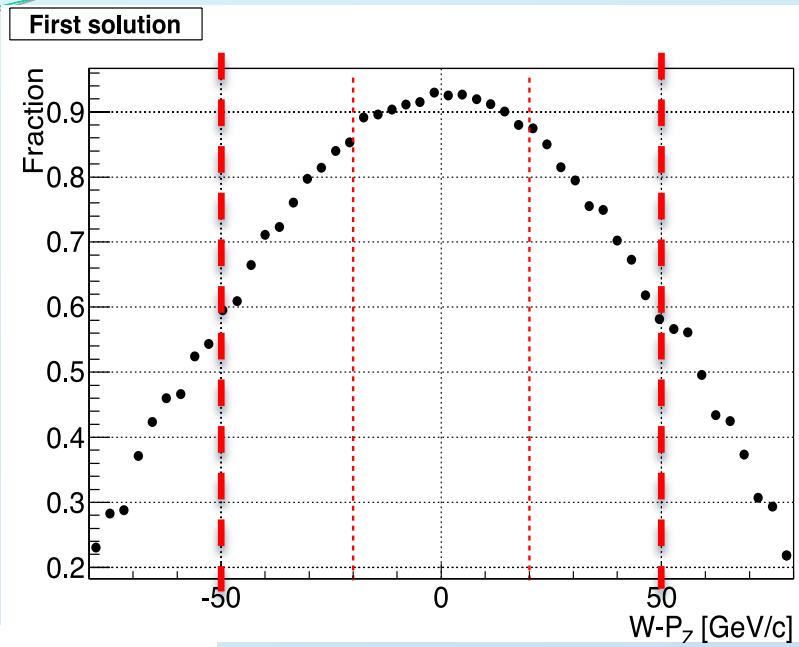
Smaller |Pz| → first solution
Larger |Pz| → other solution

BOTH the first and the other solution can have misreconstructed events!

RIKEN

FIRST SOLUTION for Pz

STAR analysis: S.Fazio



We select **the first solution → better** ***Fraction of correctly reconstructed events***

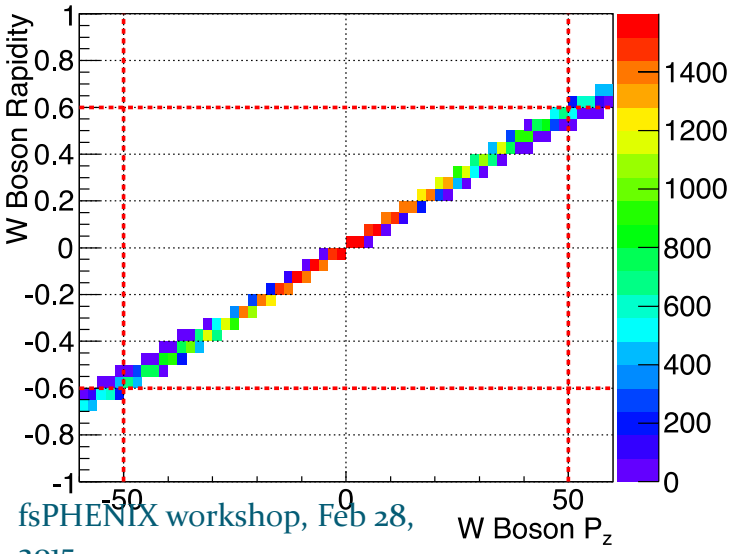
$|P_L|$ < 50 GeV → < 40 % misreconstructions

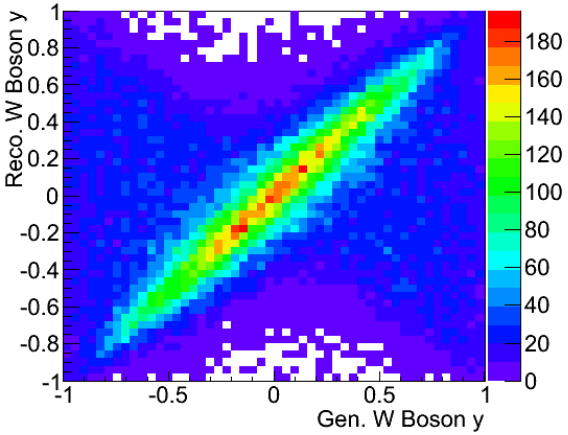
How do we estimate the fraction?

Answer: we take the # events where Pz is reconstructed within +/- 30 GeV

NOTE: We **only** use the first solution. This can be improved at a later stage.

We cut at |Pz| < 50 GeV → |W-y| < 0.6 to minimize misreconstructions

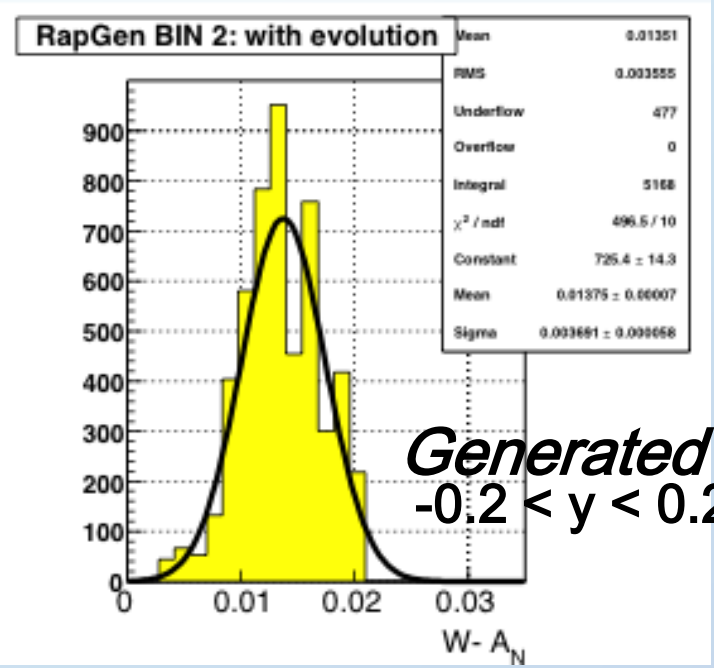


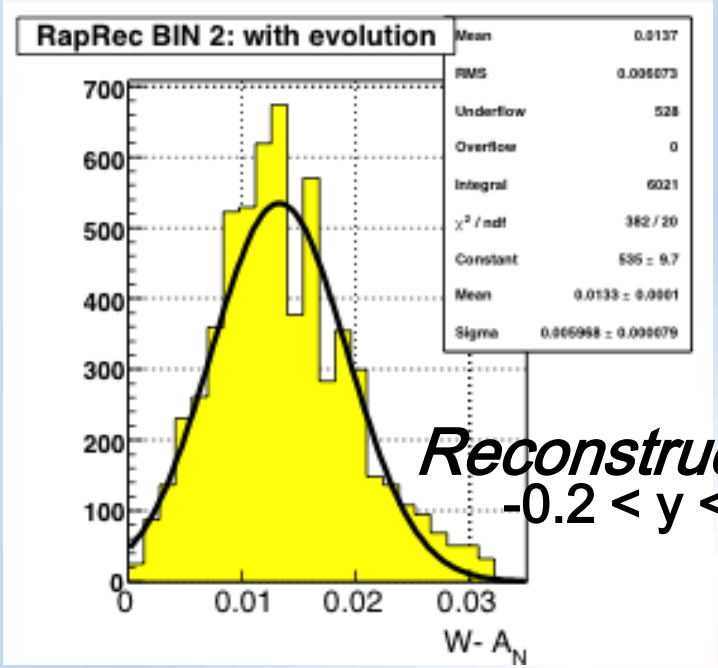


MC challenge - systematics

STAR analysis: S.Fazio

- Tables (W rapidity-P_T bins) for A_N prediction with evolution given by Z-B Kang [arXiv:1401.5078]
- Use PYTHIA MC prediction for W^- (the A_N prediction is always positive)
- Assign each prediction value from the tables according to the generated values of W-rapidity and P_T
- After the event is fully reconstructed we look at the P_T distributions of A_N





- We fit a Gaussian distribution and compare the means
- We rely on the fact that the input asymmetry has the same dependence as the

The same is done for W-P_T

W Asymmetry

STAR analysis: S.Fazio

- ✓ First we calculate the asymmetries for each beam separately
- ✓ Then we combine the two asymmetries
- ✓ We fit sin(ϕ) modulation with phase = π/2
- ✓ **Average RHIC polarization** for 2011 transverse p-p data → **P = 53%**

$$A_N \approx \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

We use the "square root formula" to cancel dependencies on geometry and luminosity

$$A_N \approx \frac{1}{P} \frac{\sqrt{N_R{}^{\uparrow} N_L{}^{\downarrow}} - \sqrt{N_L{}^{\uparrow} N_R{}^{\downarrow}}}{\sqrt{N_R{}^{\uparrow} N_L{}^{\downarrow}} + \sqrt{N_L{}^{\uparrow} N_R{}^{\downarrow}}}$$

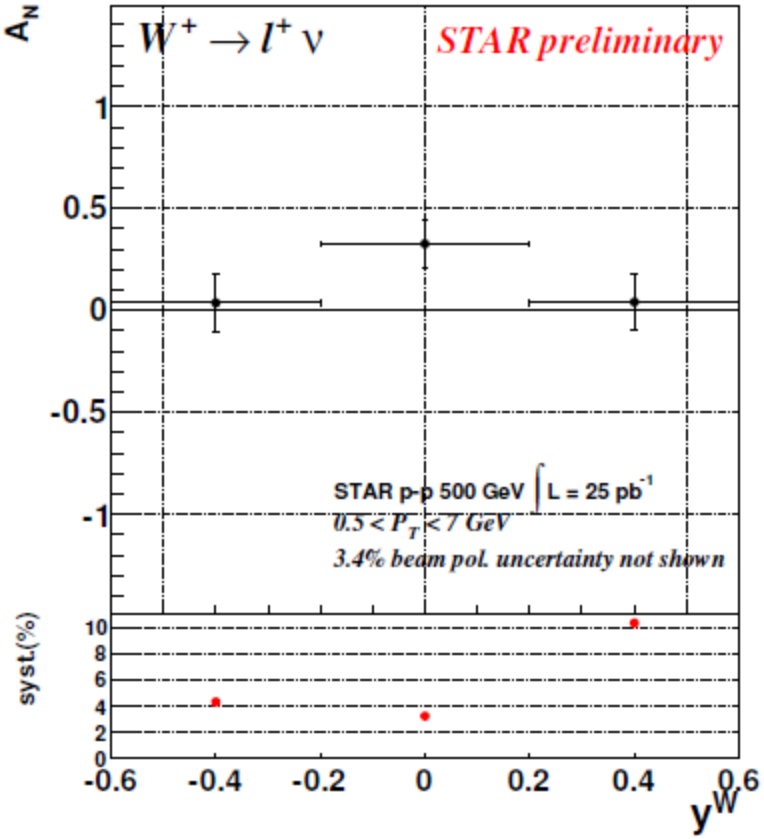
Asymmetries measured:

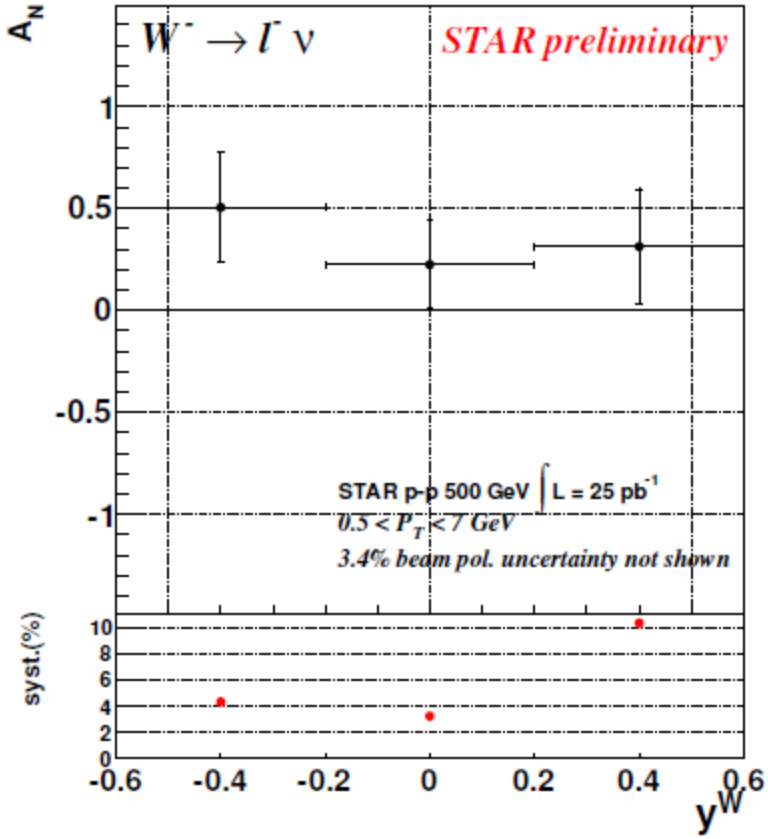
- **Signal sample asymmetry**

In backup slides:

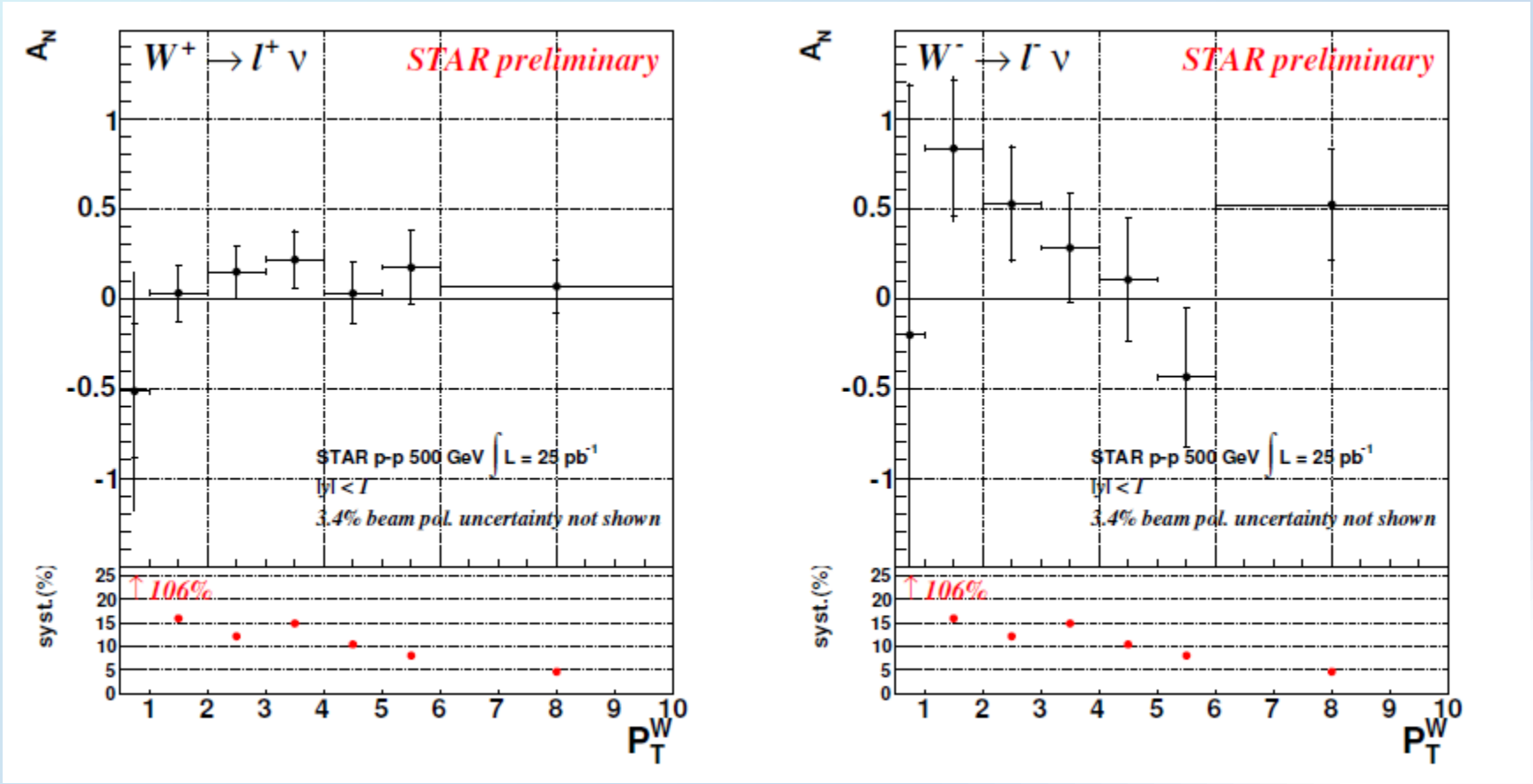
- Geometrical effects asymmetry
- Luminosity effects asymmetry

STAR results





STAR results



Open questions

- Can sPHENIX properly reconstruct 40 GeV electrons?
  - Charge id still possible?
- Do multiple collisions interfere with recoil reconstruction?
- How well can fsPHENIX reconstruct the recoil?
  - Dependence on acceptance
  - Dependence on detector hardware

- Closely related ePHENIX CC DIS (ep→νX)

Work needed

- Electron reconstruction:
  - Pythia W simulation → (f)sPHENIX sim→reco
- Recoil:
  - Acceptance dep: Pythia 9W simulation
  - Detector dep: realistic fsPHENIX sim
  - Pileup → merge multiple MB events with signal?
- Background:
  - W→tau MC, default MinBias →fsPHENIX sim
- CC DIS:
  - CC + diffractive Pythia →ePHENIX sim